MAJORANA MASSES FOR NEUTRINOS IN SO(10)

in Proceedings of the Second International Workshop on Neutrino Telescopes, Venice 1990

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The experimental values of $\alpha(M_w), \sin^2\theta_w(M_w)$ and $\alpha_s(M_w)$[1]:

$$\alpha(M_w) = 1/128$$

$$\sin^2\theta_w(M_w) = 0.228 \pm .004 \tag{1}$$

$$\alpha_s(M_w) = 0.107^{+.013}_{-.009}$$

are such that the gauge coupling $\alpha_3(t), \alpha_2(t)$ and $\alpha_1(t)$ of the standard group $G = SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ evolve as shown in fig.1.

Consequently they cross at three different scales . In unified models with gauge group $SO(10)$[2] it is not possible to break SO(10) directly to G with only one of the smallest irreducible representations for the Higgs scalars . In fact, as we can see in table 1, all the singlets in these representations have symmetry group larger than G[3]. So, we expect at least two energy scales for the spontaneous symmetry breaking such that at the highest scale (M_X) SO(10) breaks down to G' and then, at M_R, G' breaks to the standard group G. If G' contains $SU(2)_R$ and/or $SU(4)_{PS}$ (in SO(10) $Y = T_{3R} + \frac{B-L}{2}$) we may obtain the unifi-

cation of the α_i with an appropriate choice of M_R and M_X . We have the following possibilities for $G'^{[4]}$:

TABLE 1

G'	Highest VEV in the
$SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R \times D$	54
$SU(4)_{PS} \otimes SU(2)_L \otimes SU(2)_R$	$\Phi_T = A_{78910} \in 210$
$SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \times D$	$\Phi_L = \frac{1}{\sqrt{3}}(A_{1234} + A_{3456} + A_{1256}) \in 210$
$SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$	$\cos\theta\Phi_L + \sin\theta\Phi_T \in 210$
	$(\sin 2\theta \neq 0)$

In all these cases the breaking scale M_X is not higher than the scale at which α_2 and a_3 joint in fig.1 . In fact, if G' contains $SU(4)_{PS}$, α_3, alias α_4, decreases faster above M_R and meets α_2 earlier . If G' contains D[5], the left-right symmetry at the highest scale implies the existence of scalars with non trivial properties under $SU(2)_L$ with masses $\sim M_R$ (this because it is necessary the existence of scalars with masses $\sim M_R$ and non trivial properties under $SU(2)_R$ to break this symmetry at M_R). Because of the contributions of these scalars, α_{2L} decreases smoother above M_R and so the unification point with α_3 is lower again. As a conclusion we get,at first loop, the upper limit on M_X[6]:

$$M_x \leq M_w \exp\frac{\pi}{2}(\frac{\sin^2\theta_w(M_w) - \frac{\alpha}{\alpha_s}(M_w)}{\alpha(M_w)}) = 2.76 \cdot 10^{15} \cdot 8^{0\pm1} \qquad (2)$$

corresponding to $\tau_p \leq 1.6 \cdot 10^{33} \cdot 8^{0\pm4}$.

The uncertainties depend on the present errors on $\sin^2\theta_w(M_w)$ and $\alpha_s(M_w)$.

If the breaking of the G' symmetry is induced by the VEV of the 126 (and $\overline{126}$), the Yukawa couplings f_i of the fermions of the 16 ($\overline{16}$) give rise to Majorana masses for the left-handed antineutrinos of the i-th family given by :

$$M_{\overline{\nu}_{Li}} = f_i < 126 >= \frac{f_i}{g_{2R}(M_R)} M_R. \tag{3}$$

From the see-saw mechanism[7] and (3) we obtain :

$$\begin{aligned} M_{\nu_{\tau_L}} &= \frac{g_{2R}}{f_3}(\frac{10^{11}GeV}{M_R})(\frac{m_t}{100GeV})^2 10eV \\ M_{\nu_{\mu_L}} &= \frac{g_{2R}}{f_2}(\frac{10^{11}GeV}{M_R})2 \cdot 10^{-3}eV \\ M_{\nu_{e_L}} &= \frac{g_{2R}}{f_1}(\frac{10^{11}GeV}{M_R})2 \cdot 10^{-10}eV. \end{aligned} \tag{4}$$

If the spontaneous breaking of G' is induced by the scalars of the 16 (and $\overline{16}$) which cannot have Yukawa couplings to the fermions, one predicts Majorana masses for the left-handed antineutrinos (neutrinos) smaller (larger) by several orders of magnitude[8]. In Table 2, for the models with $SU(2)_R \subset G'$, we report the values of τ_p and $\mu = \frac{10^{11}GeV}{M_R} 10eV$ deduced evaluating M_X and M_R from the renormalization group equations at first (in brakets) and second loop approximation with the contributions of the scalar multiplets required by symmetry (the multiplet under G' containing $< 126 >$ above M_R and the electroweak Higgs above M_w). For the last possibility in Table 2 we have taken for θ the value chosen in ref.[4]; however, also different values for θ have been considered[9] and the corresponding values of M_X (M_R) may at most increase (decrease) by 10% (50%).

As we can see the present uncertainty on the values of $\sin^2\theta_w(M_w)$ and $\alpha_s(M_w)$ implies a big uncertainty for the predicted proton lifetime. Nevertheless we can draw some conclusions; the model with $SU(4) \otimes D \subset G'$ appears, at the second loop approximation, inconsistent with the experimental lower bound

$$(1-30) \cdot 10^{31} years \leq \tau(p \to e^+\pi^0). \tag{5}$$

(in all these models, with $SU(2)_R \subset G'$, $Br(p \to e^+\pi^0) \sim 30\%$.) The model with $SU(3) \otimes U(1) \otimes D \subset G'$ is consistent with (5) only if $\sin^2\theta_w(M_w)$ and/or α_s are larger than the central values in (1). Finally the models with $D \not\subset G'$ are consistent with (5), especially the one with $SU(3) \otimes U(1) \otimes G'$, which, at first loop, predicts for M_X the upper limit in (2). The present error on α_s has twice the effect of the error on $\sin^2\theta_w(M_w)$ on the determination of M_X . The e$^+$ e$^-$ experiments will soon give a more precise determination of $\sin^2\theta_w(M_w)$; therefore we study the relationship between $\sin^2\theta_w(M_w)$, M_R, and M_X in the various models. For $G' = SU(3) \otimes SU(2) \otimes SU(2) \otimes U(1)$ one has at first loop :

$$\ln\frac{M_R}{M_w} = \frac{\pi}{\alpha}(\frac{3}{8} - \sin^2\theta_w(M_w))\frac{16}{17} - \frac{19}{17}\ln\frac{M_x}{M_w} \tag{6}$$

if we define M_x^0 the value corresponding to the lower limit for τ_p one gets from (6) the upper limit for M_R:

$$M_R \leq M_w(\frac{M_w}{M_x^0})^{\frac{19}{17}} \exp[\frac{\pi}{\alpha}(\frac{3}{8} - \sin^2\theta_w(M_w))\frac{16}{17}]. \tag{7}$$

In this way we get for the different models a lower limit for μ as a function of the lower limit on τ_p (see Table 3).

In conclusion we see that the lower limit on μ is an increasing function of the lower limit on τ_p. If the intermediate symmetry G' is broken by the VEV of the 16, higher values are expected for the masses of the left-handed neutrinos.

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